

# Dayside Flow Bursts in the Earth's Magnetosphere

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**Abstract.** Observations from Polar/Thermal Ion Dynamics Experiments indicate the presence of cold magnetospheric/ionospheric  $H^+$  and  $He^+$  in the vicinity of subsolar magnetopause. These cold ions were accelerated to a perpendicular speed  $V_{\perp B}$  of as high as 150 km/s toward the magnetopause,  $\sim 6$  mV/m in convection electric field and carried  $\sim 1$  ions/cm<sup>3</sup> in number density or  $\sim 8 \times 10^7$  ions cm<sup>-2</sup> s<sup>-1</sup> in particle flux or  $\sim 3 \times 10^{26}$  ions s<sup>-1</sup> in transferring rate assuming sunward convecting flux tube with latitudinal cross-section of  $1 R_E$  in width and  $10 R_E$  in length along magnetopause. The rate of plasma transfer from inside the magnetopause is significant compared with  $1 \times 10^{27}$  ions s<sup>-1</sup> entering LLBL with the same incident cross-section on the magnetopause from the solar wind. The occurrence of these flow bursts events is sensitive to the orientation of IMF. It is suggested that the magnetospheric/ionospheric ions contribute and dynamic response to the physical processes such as magnetic reconnection and plasma instabilities in the subsolar magnetopause boundary layers.

## 1. Introduction

Plasma in the Earth's magnetosphere has two major sources, the solar wind and the ionosphere. The former enters first at the magnetopause when the magnetospheric magnetic field open to the solar wind, where it forms the low latitude boundary layer and high-latitude boundary layer (plasma mantle). Ionospheric plasma directly populates closed magnetic flux tubes and forms plasmasphere or populates open magnetic flux tubes at the cusp/cleft creates ion fountain. Magnetospheric convection then brings these two populations interact with each other in the boundary layers... The plasma in the dayside magnetosphere may come from the detachment of plasmaspheric ions [Chappell, 1974]... The last closed magnetic flux tubes convected to the subsolar magnetopause could bring plasmaspheric particle toward the magnetopause...

While observations at the energy range of hundreds of eV to KeV are ample, observations of cold plasma of few to few tens of eV with optimal energy resolution are lacking. Particularly when the estimate of plasma moments of these ions are crucial to theoretical and numerical modeling efforts...

We use data from the Thermal Ions Dynamics Experiments (TIDE) [Moore *et al.*, 1995] on Polar spacecraft during the years of 2001 and 2002 when its apogees were near the equatorial plane to study the dynamics of cold ions with the energy range between the spacecraft potential of few eV and 375 eV in dayside magnetopause boundary layers. TIDE instrument has the time

resolution of  $\sim 6$  s and the energy resolution of up to 5% which provides good estimates of plasma moments for cold ions such as  $H^+$ ,  $He^{+2}$ ,  $He^+$ ,  $N^+$ ,  $O^{+2}$  and  $O^+$  that have relatively narrow thermal spreadings provided the peak energies of these ions falls in the energy range of the instrument. In this study, we only use STOPS component in TIDE, which only provides collapsed three dimensional measurements in the spin plan, since the STARTS component, which provide three dimensional measurements, was not functioning after late 1996. All the possible effects of the collapsing the three dimensional into two dimensional measurement have been considered carefully while performing the analysis. With the extended energy range and good energy and time resolutions, these measurements will add to our already profound knowledge of plasmas in the dayside magnetospheric boundary layers.

## 2. Observations and Analysis

Combining the ion measurements from TIDE/STOPS, and magnetic field from magnetic field Investigation (MFI) [Russell, *et al.*, 1995] on Polar spacecraft and solar wind parameters from WIND and ACE, we surveyed all the Polar apogee passes in the years of 2001 and 2002 when the spacecraft was at dayside and near the equatorial plane. Important signatures which we paid attention to in selecting these events: long period of clearly identified magnetosheath interval at the beginning or the end of the event to ensure that the spacecraft was near the magnetopause, multiple magnetopause crossings to ensure the spacecraft stayed near the magnetopause for a relatively long period of time, and evanescences of ion fluxes inside the magnetopause. A total of 17 events were selected and studied in detail.

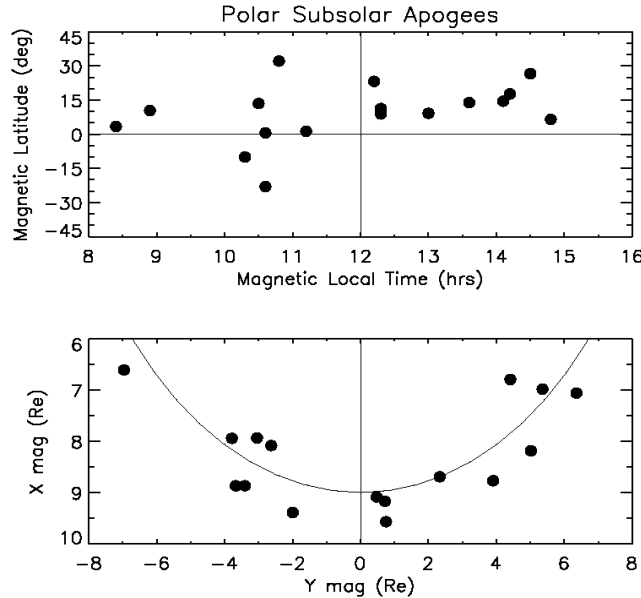


Figure 1 shows the positions of magnetopause crossings by Polar in our data set. Each point indicates the mid-point of the first and last magnetopause crossings for each event. Each event contains multiple magnetopause crossings that span as long as 3 hours. The orbital coverage of the event studied range from 6 to 18 hours in magnetic local times and within  $\pm 45^\circ$  in magnetic latitudes. Nominal position of magnetopause in the collection of the events is shown. The magnetopause position at subsolar is  $9 R_E$  compared with the typical position at  $10 R_E$ . On average the magnetopause is slightly compressed in our data set.

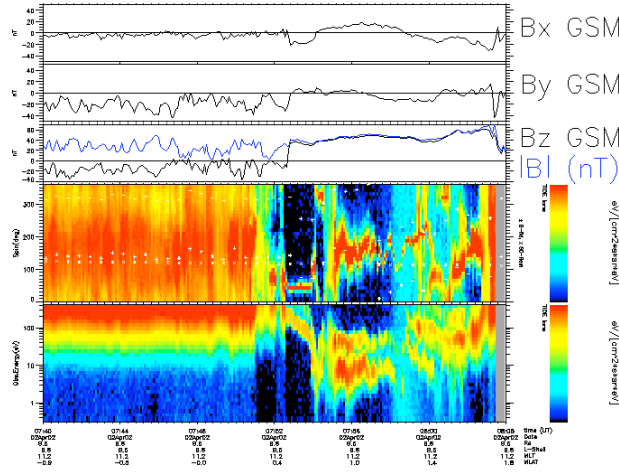


Figure 2 shows magnetic field components in GSM coordinate and TIDE/STOPS ion spectrogram in spin-angle vs. time (upper panel) and energy vs. time (lower panel) for the event on April 2, 2002. The magnetic field direction (+ sign), opposite direction ( $\square$  sign) and spacecraft moving direction ( $\square$  sign) in the upper panel are overlaid. The color bar indicates the differential flux in ions  $\text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1} \text{eV}^{-1}$  in logarithmic scale. The saturate fluxes at the beginning of the interval indicates magnetosheath. The fluxes then dispersed to lower energies while the spacecraft went into the magnetosphere. As denoted the interval when the flow bursts observed were near the start of multiple magnetopause crossings that followed. The spacecraft were near 11 hours in magnetic local time and near  $0^\circ$  in magnetic latitude.

Figure 3 shows the schematics of how ion species are identified using TIDE/STOPS data.  $\text{He}^+$  ( $\text{O}^+$ ) has  $E=m/q$  ratio of 4 (16). If observed, there should be peaks at twice (Four time) the velocity of  $\text{H}^+$ .

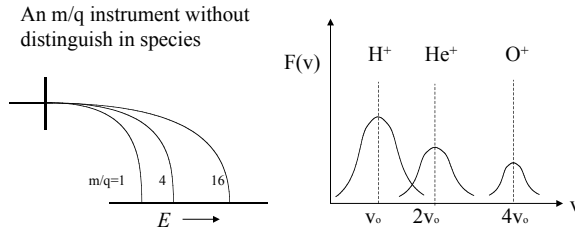
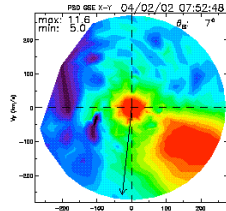
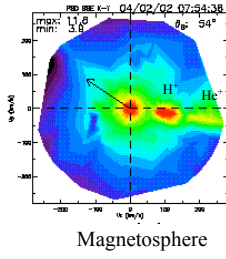


Figure 4 shows the ion velocity distribution functions for the event shown in Figure 2. The spin plan of the spacecraft is mostly aligned with X-Y GSE plan. Magnetic field projection are shown in solid (above the spin plan) or dashed arrows (below the spin plan). The angles of the magnetic fields to the spin plans are printed at the upper right corners. The color scale used in each panel are different in order to see the details. From left to right, the figure shows the 3-s snapshots of ion velocity distributions for the intervals of magnetosphere, LLBL and magnetosheath. In the magnetosphere, two species are identified:  $\text{H}^+$  and  $\text{He}^+$ . In the LLBL, it shows a mixture of these species with diverted magnetosheath flows. Since Polar was near the equatorial plane and was not far away from the subsolar point (11.2 MLT), the magnetosheath flows mainly duskward at a speed of  $\sim 150 \text{ km s}^{-1}$ .

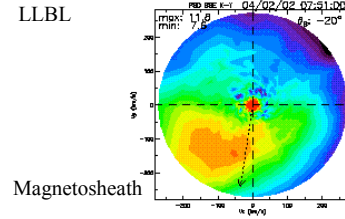
April 2, 2002, 07:50 - 08:00

• IMF: (-4, 1, 2) nT

Polar/TIDE  
X-Y GSE



LLBL

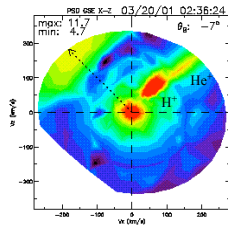


Magnetosheath

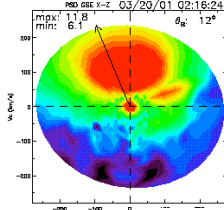
Figure 5 shows the ion velocity distribution functions for the event on March 20, 2001 when the spin plan of the spacecraft is more or less aligned with X-Z GSE plan. The format of the figure is the same as Figure 3. In the magnetosphere, in addition to  $H^+$  March 20, 2001, 02:30 - 03:00

Polar/TIDE  
X-Z GSE

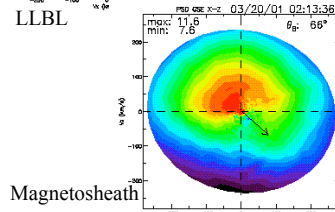
• IMF : (0, -12, -8) nT



Magnetosphere



LLBL



Magnetosheath

and  $He^+$  there is a component of magnetosheath flow accelerated northward along the magnetic field. In the LLBL, a mixture of cold magnetospheric and magnetosheath species is seen.

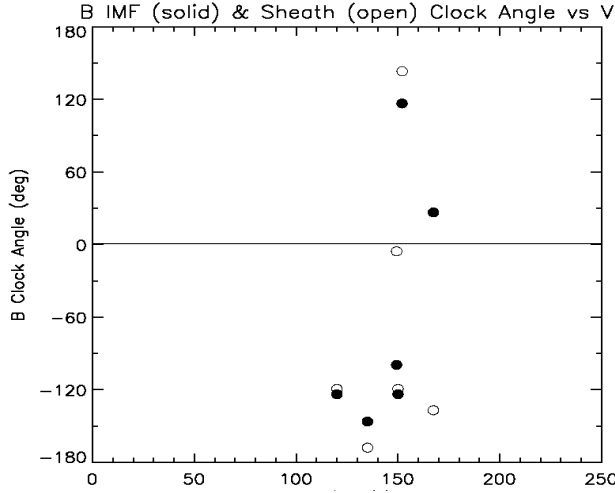
Table 1 summarizes the plasma moments, averaged solar wind dynamic pressure, and  $Kp$  index obtained from the observation. The plasma moments, except temperature, are calculated by integrating the corresponding quantities in the energy range above spacecraft potential and the upper limit of the instrument. The temperature is obtained by fitting a Maxwellian distribution to the data in that energy range and therefore only representing cold/core part of the magnetospheric population.

$N, cm^{-3}$	1-10
$T_{core H}, eV$	3 - 10
$V, km/s$	$150 \pm 30$
$ B , nT$	$40 \pm ?$
$E, mV m^{-1}$	$4 \pm 1.2$
$P_{dyn}, nPa$	
$Kp$	

\* fitted to a single Maxwellian distribution function for  $H^+$  within the optimal energy range of TIDE instrument

Figure 6 shows the events when flow bursts observed as a function of magneotheath (solid circles) and IMF (open circles)

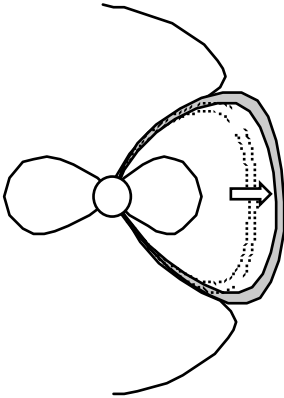
clock angles. Most flow bursts occur when the clock angles are near  $\pm 180^\circ$  or southward.



### 3. Discussion

To summarize, we estimated the particle flux of the sunward flow bursts at  $\sim 8 \times 10^7$  ions  $\text{cm}^{-2} \text{s}^{-1}$  during low to medium geomagnetic activities, the ions compose of  $\text{H}^+$  (>90%),  $\text{He}^+$  (<10%), and possibly trace of  $\text{O}^+$ , and the convection electric field of 6 mV/m compared with the average of 0.4 mV/m during time of medium magnetic activities in the outer magnetosphere [Rowland and Wygant, 1998]. Assuming the total cross section of the sunward flow bursts carried by a flux tube of the size of  $\sim 1 R_E$  in width and  $\sim 10 R_E$  in length measured between northern and southern cusp bifurcation points is  $10 R_E^2$ , the number of particle flux brought to the dayside magnetopause is  $\sim 3 \times 10^{26}$  ions  $\text{s}^{-1}$ .

Chappell et al. [1970] discovered the ratios of ion composition at  $\text{H}^+$  (99%),  $\text{He}^+$  (1%),  $\text{O}^+$  (0.1%) using OGO-5 data. Freeman [1977] estimated the sunward convection of  $\sim 10^8$  ions  $\text{cm}^{-2} \text{s}^{-1}$  using data from Geosynchronous satellite. The flux impinging on a merging area at the magnetopause of  $\sim 5 R_E^2$  [Heikkila, 1975] would yield  $\sim 10^{27}$  ions  $\text{s}^{-2}$ .



Elphic et al. [1997] applied the model of Rasmussen et al. [1993] and estimated the particle fluxes at geosynchronous orbits of  $10^{26}$  ions  $\text{s}^{-1}$  at high latitudes ( $\geq 25^\circ$  to north and south) and  $2.7 \times 10^{26}$  at low latitudes ( $< 25^\circ$  north and south) assuming an area of  $15^\circ$  in longitude and down to  $2 R_E$  in altitude along the field lines.

Ionospheric ion outflow [Chappell et al., 1987; Moore et al., 1999]:  $\sim 10^8$  ions  $\text{cm}^{-2} \text{s}^{-1}$  (quiet time) to  $10^{10}$  ions  $\text{cm}^{-2} \text{s}^{-1}$  (high

magnetic activities). The rate of ion outflow is  $\sim 10^{25}$  ions  $s^{-1}$  during quiet time and above  $\sim 10^{26}$  ions  $s^{-1}$  during high magnetic activities.

	Gain from Ionosphere, ions $s^{-1}$	Convect toward Magnetopause, ions $s^{-1}$	Merge into LLBL, ions $s^{-1}\dagger$	Enter LLBL from Solar Wind, ions $s^{-1}\ddagger$
Chappell et al. (Polar Wind, OGO-5)	$1.5 - 5 \times 10^{26}$			
Moore et al. (Ion outflows, POLAR)	$10^{25} - 10^{26}$			
Freeman (Plasmasphere, GEOS)		$10^{27}$		
Elphic et al. (Plasmasphere, GEOS)		$2.7 \times 10^{26}$		
Chappell et al. (Plasma trough, OGO-5)		$3 \times 10^{25} - 1.3 \times 10^{26}$		
This study (Magnetopause, POLAR)			$3 \times 10^{26} \dagger$	
Heikkila (model)				$1 \times 10^{27} \ddagger$

$\dagger$  per  $10 R_E^2$ :  $1 R_E$  in width by  $10 R_E$  in length in latitudinal cross-section of a flux tube along the magnetopause

$\ddagger$  assuming  $n_{sw} \sim 7 \text{ cm}^{-3}$ ,  $v_{sw} \sim 400 \text{ km s}^{-1}$ ,  $B_{IMF} \sim 5 \text{ nT}$ ,  $E_{sw} \sim 1.4 \text{ mV m}^{-1}$ ,  $A_{incident} \sim 10 R_E^2$

Table 2 shows the gain and lost of ions that are ionospheric origin in the dayside magnetosphere. Although the cross section of the flow burst are a big factor (assumed  $10 R_E$ ) in calculating the rate of ion source, it is comparable to what have been observed in the other parts of the dayside magnetosphere.

Interestingly the lost rates of plasma sheet particles to the auroral zone falls between  $10^{25}$  and  $10^{26}$  ions  $s^{-1}$  [Hill, 1974; Pilipp and Morfill, 1976]. Although the solar wind and ionospheric ions are the two comparable parts of the plasma population in the plasmasheet, it indicates that the global circulation of mass flows are scaled to  $\sim 10^{26}$  ions  $s^{-1}$  or  $\sim 600 \text{ kg hr}^{-1}$  assuming protons.

Finally,...

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